
Contents

List of Figures	xi
List of Tables	xix
Preface.....	xxi
About the Authors	xxiii
List of Abbreviations	xxv
Acknowledgments	xxxi
1 Introduction	1
1.1 Technology Overview.....	1
1.2 System Configurations.....	4
1.3 Evolution of Infrared Communication Systems	10
1.4 The Optical Wireless Channel	17
1.5 Design Fundamentals.....	20
1.6 Power Budget Considerations	21
1.7 Summary and Conclusions.....	22
2 Atmospheric Transmission Limitations	25
2.1 Introduction to Atmospheric Propagation	25
2.2 Important Definitions	26
2.2.1 Atmosphere	26
2.2.2 Aerosol	27
2.2.3 Attenuation	29
2.2.4 Absorption	29
2.2.5 Scattering.....	30
2.2.6 Radiance	32
2.3 Atmospheric Transmission.....	33
2.4 Effect of Rain, Fog, and Mist	34
2.5 Scintillation	38
2.6 Summary and Conclusions.....	40

3	Data Transmission Limitations and Eye Safety	43
3.1	Data Transmission Limitations.....	43
3.1.1	Ambient Illumination Noise	44
3.1.1.1	Direct and Reflected Sunlight	49
3.1.2	Multipath Dispersion	57
3.2	Eye Safety	60
3.3	Extended versus Collimated Sources.....	61
3.3.1	Class 1 Lasers	62
3.3.2	Class 2 Lasers	63
3.3.3	Class 3 Lasers	63
3.4	Holographic Diffusers	63
3.5	Light-Emitting Diodes versus Laser Diodes.....	66
3.6	Special Considerations for Outdoor Systems.....	67
3.7	Summary and Conclusions.....	70
4	Fundamentals of Optical Concentration.....	73
4.1	Overview	73
4.2	Geometrical Optics and Ray Tracing.....	74
4.2.1	Snell's Laws	75
4.3	Optical Path Length and Fermat's Principle	78
4.4	The Étendue or Lagrange Invariant.....	78
4.5	The Edge Ray Principle.....	83
4.6	Concentration Ratio	84
4.6.1	Different Versions of Concentration Ratio	86
4.7	Summary and Conclusions	87
5	Optical Concentrators.....	89
5.1	Overview of Optical Concentrators	89
5.2	Wireless IR Receiver Requirements	90
5.3	Optical Filters.....	91
5.4	Optical Concentrators	97
5.4.1	Ideal Concentrators	100
5.4.2	Imaging Concentrators and Fresnel Lenses	101
5.4.3	Hemispherical Concentrators	103
5.4.4	Compound Parabolic Concentrators	104
5.4.5	Dielectric Totally Internally Reflecting Concentrators (DTIRCs).....	106
5.5	DTIRC Characteristics.....	109
5.5.1	Geometrical Gain.....	109
5.5.2	Maximum Output Angle	112
5.5.3	Total Height.....	115
5.6	Comparison of Concentrators.....	117
5.7	Practical Issues.....	122

5.8	Other Shapes of DTIRCs	125
5.8.1	Parabolic DTIRC.....	126
5.8.2	Elliptical DTIRC	132
5.8.3	Comparison of DTIRCs.....	133
5.9	Summary and Conclusions.....	139
6	Optical Wireless Transmitter Design.....	143
6.1	Introduction to Optical Wireless Transceiver Design	143
6.2	Transmitter Design Considerations	145
6.3	Optical Source Characteristics.....	146
6.4	Types of Optical Modulation.....	151
6.4.1	External Optical Modulators.....	154
6.4.2	Direct Digital Modulator	157
6.4.3	Direct Analog Modulator.....	160
6.5	Driver Circuit Design Concepts	162
6.5.1	Driver Specifications	163
6.6	Current Steering Output Circuit	164
6.7	Back Termination Circuit.....	165
6.8	Predriver	166
6.9	Data Retiming.....	168
6.10	Automatic Power Control	168
6.11	Transmitter Linearization Techniques	170
7	Optical Wireless Receiver Design	173
7.1	Receiver Design Considerations.....	173
7.2	Photodetection in Reverse-Biased Diodes	174
7.3	Choosing the Photodetector	176
7.4	Receiver Noise Considerations.....	180
7.5	Bit Error Rate and Sensitivity	183
7.6	Bandwidth.....	184
7.7	Signal Amplification Techniques	185
7.7.1	Low-Impedance Front End	187
7.7.2	High-Impedance Front End	187
7.7.3	Transimpedance Front End.....	188
7.7.4	Bootstrap Transimpedance Amplifier.....	190
7.8	Receiver Main Amplifier (RMA).....	193
7.8.1	Optimization Decision Circuit.....	196
7.8.2	Loss of Signal Detector (LSD).....	198
7.9	Transceiver Circuit Implementation Technologies: Hybrid and Monolithic Integration	199
7.9.1	OEIC for Higher Integration	202
7.10	Summary and Conclusions.....	204

8	Modulation, Coding, and Multiple Access.....	207
8.1	Introduction to Modulation and Multiple Access Techniques	207
8.2	Modulation.....	208
8.2.1	Analog Modulation.....	208
8.2.2	Pulse Modulation (PM).....	209
8.2.3	Digital Modulation	217
8.2.3.1	On-Off Keying.....	220
8.3	Modulation Techniques Comparison.....	221
8.4	Modulation Schemes in the Presence of Noise.....	228
8.5	Modulation Schemes in the Presence of Multipath Distortion.....	232
8.6	Multiple Access Techniques.....	233
8.6.1	Electrical Multiple Access Techniques.....	234
8.6.2	Optical Multiple Access Techniques.....	237
8.6.2.1	Angle-Diversity Receivers.....	240
8.6.2.2	Quasi-Diffuse Transmitters.....	243
8.7	Summary and Conclusions.....	245
9	Infrared Data Association (IrDA) Protocols	249
9.1	Wireless Protocol Standards.....	249
9.2	The Infrared Data Association	249
9.3	IrDA Standard Overview.....	251
9.4	The Physical Layer Protocol	255
9.4.1	IrDA Transmitters.....	255
9.4.2	IrDA Receivers	256
9.4.3	Transceiver Specifications.....	258
9.4.4	Other Issues Related to the Physical Layer	259
9.5	Framer and Driver	266
9.5.1	Framers	266
9.5.2	Controllers	266
9.5.3	Drivers	267
9.6	IrLAP	267
9.6.1	The IrLAP Frame	268
9.6.2	Discovery and Device Selection	269
9.6.3	Link Negotiation and Connection	269
9.6.4	Connection Establishment.....	270
9.6.5	Information Exchange and Flow Control.....	271
9.7	Link Management Protocol (IrLMP).....	271
9.8	Information Access Service and Protocol (IAS)	273
9.9	Tiny Transport Protocol (TinyTP)	274
9.10	Session and Application Layer Protocols.....	275
9.11	Summary and Conclusions.....	278

10	Wireless Infrared Networking	281
10.1	Introduction	281
10.2	Network Architecture	282
10.3	Optical Wireless Network Specifications	283
10.3.1	IEEE 802.11 Specification.....	284
10.3.1.1	Medium Access Control.....	285
10.3.1.2	Distributed Coordination Function (DCF).....	286
10.3.1.3	CSMA/CA.....	286
10.3.1.4	Acknowledgment and Reservation: RTS/CTS.....	287
10.3.2	IrDA AIr	289
10.3.2.1	AIr and IEEE 802.11	291
10.4	The Ad Hoc Network	293
10.4.1	Issues in Ad Hoc Network Design	293
10.4.2	Routing in Infrared Ad Hoc Networking.....	294
10.4.2.1	Proactive	294
10.4.2.2	Reactive.....	295
10.4.2.3	Hybrid.....	295
10.4.3	Security in Infrared Ad Hoc Networking.....	296
10.5	Quality of Service (QoS)	297
10.5.1	QoS in the MAC Layer: IEEE 802.11e	298
10.5.1.1	EDCA in IEEE 802.11e.....	299
10.5.2	QoS in Routing.....	300
10.6	Future Infrared Networking	302
	References	303
	Index	319

Figure 3.1	Latitude (summer time) in the visible and near IR regions	31
Figure 3.2	Variation of electrical power with frequency of a fluorescent lamp	35
Figure 3.3	Spectral sensitivity of a Si photodiode and transmittance of a material with longpass characteristic.....	48
Figure 3.4	Source of illumination introducing noise in a wireless IR receiver	49
Figure 3.5	Solar illumination on a wireless IR link: (a) direct solar collimation and (b) reflected solar conjunction	50
Figure 3.6	Spectrum of the solar radiation outside the Earth's atmosphere in the visible and near-IR regions.....	51
Figure 3.7	Solar disk and its atmospheric diffraction corona.....	52
Figure 3.8	Atmospheric conditions on a wireless infrared link: (a) scattering in clouds and (b) scattering in fog.....	56